Volume 37 April, 1951 *Number 4*

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

GEAR OIL ADDITIVES

PUBLISHED BY

THE TEXAS COMPANY

TEXACO PETROLEUM PRODUCTS

TEXACO LUBRICANTS FOR INDUSTRIAL GEARS

TYPE OF GEAR	DESCRIPTION	AMBIENT TEMPERATURES	NORMAL OPERATION	HEAVY DUTY, WHERE EXTREME PRESSURE LUBRICATION REQUIRED	IN PRESENCE OF WATER OR CHEMICALS
SPUR, BEVEL, SPIRAL BEVEL, ANNULAR OR INTERNAL	Gears enclosed, casings oil tight, bearings separately lubricated.	Below 40° F.	Thuban 80 Regal Oil PC (R&O)	Meropa Lubricant—1	
		40° to 100° F.	Thuban 90 Regal Oil G (R&O)	Meropa Lubricant—3	
		Above 100° F.	Thuban 140	Meropa Lubricant—6	
	Gears enclosed, casings oil tight, gear lubricant to serve bearings as well.	Below 40° F.	Regal Oil F (R&O) Algol Oil Altair Oil	Meropa Lubricant—1	
		40° to 100° F.	Regal Oil G (R&O) Ursa or Aries Thuban 90	Meropa Lubricant—1 or 2	
		Above 100° F.	Regal Oil H (R&O) Ursa Oil Heavy Auriga or Thuban 90	Meropa Lubricant—3	
	Gears entirely exposed, hand lubricated.	Below 40° F.	Crater 1 or 2-X Fluid	Meropa Lubricant—2 or 3	Crater A
		40° to 100° F.	Crater 1, 2 or 2-X Fluid	Meropa Lubricant—3 or 4	Crater 1-X, 2-X or 2-X Fluid
		Above 100° F.	Crater 3 or 5-X Fluid	Meropa Lubricant—6	Crater 2-X or 2-X Fluid
	Gears exposed, bath lubricated.	Below 40° F.	Regal Oil G (R&O) Thuban 90	Meropa Lubricant—3	
		40° to 100° F.	Thuban 140 or 250 Crater 00, 0 or 2-X Fluid	Meropa Lubricant—6 or 7	Crater A
		Above 100° F.	Thuban 250 Crater 0, 1, 2 or 2-X Fluid	Meropa Lubricant—7	Crater 1-X or 2-X Fluid
HELICAL OR HERRINGBONE	Gears enclosed, casings oil tight, bearings separately lubricated.	Below 40° F.	Regal Oil G (R&O) Thuban 90	Meropa Lubricant—3	
		40° to 100° F.	Regal Oil G (R&O) Ursa or Aries Thuban 90 or 140	Meropa Lubricant—3 or 6	
		Above 100° F.	Thuban 140	Meropa Lubricant—6	
	Gears enclosed, casings oil tight, gear lubricant to serve bearings as well.	Below 40° F.	Regal Oil PE (R&O) Algol or Altair	Meropa Lubricant—1	
		40° to 100° F.	Regal Oil F (R&O) Ursa or Aries	Meropa Lubricant—1 or 2	
		Above 100° F.	Regal Oil G (R&O) Ursa Oil Heavy, Auriga or Thuban 90	Meropa Lubricant—6	
	Gears entirely exposed, hand lubricated.	Below 40° F.	Crater 0, 1 or 2-X Fluid	Meropa Lubricant—6	Crater 1-X or 2-X Fluid
		40° to 100° F.	Crater 1, 2 or 2-X Fluid	Meropa Lubricant—6 or 7	Crater 1-X, 2-X or 2-X Fluid
		Above 100° F.	Crater 1, 2 or 2-X Fluid	Meropa Lubricant—7	Crater 1-X, 2-X or 2-X Fluid
	Gears exposed, bath lubricated.	Below 40° F.	Regal Oil G (R&O) Thuban 90	Meropa Lubricant—3	Crater A
		40° to 100° F.	Thuban 140 or 250 Crater 00, 0 or 2-X Fluid	Meropa Lubricant—6 or 7	
		Above 100° F.	Thuban 250 Crater 00, 0 or 2-X Fluid	Meropa Lubricant—7	

(Continued on Inside Back Cover)

LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

Published by

The Texas Company, 135 East 42nd Street, New York 17, N. Y.

Vol. XXXVII April, 1951 No. 4

GEAR OIL ADDITIVES

THE extensive use of additives in gear oils is not new. Actually it began about 1930 and paralleled the commercialization of the hypoid type gear. Long before this, however, fatty materials of natural origin were used. In the early days of the machine age they functioned as the sole lubricant for crude gears. Today, such materials are an important class of gear oil additives.

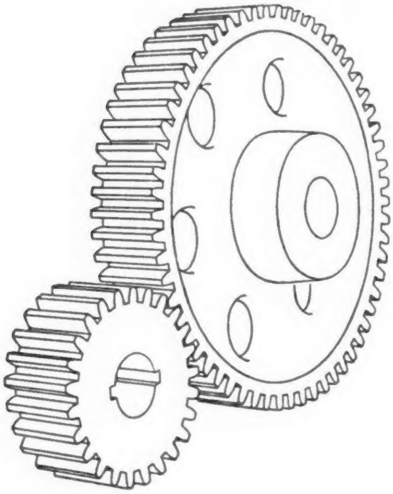
Gearing—probably one of the oldest mechanisms for transmission of power, is also in its modern form probably one of the most controversial with regard to lubrication. The capacity of metallic gears was made use of by machine designers when the petroleum industry had developed sufficiently to furnish dependable lubricants which would effectually protect gear tooth surfaces from wearing too rapidly. Even from the days of the crude wooden toothed gears, it was known that some form of greasy lubricant would prevent noise. Wear was not too serious a factor in those days as speeds were low and gear tooth loads were not excessive; animal fats served the purpose just as they also served to lubricate the bearings of contemporary machinery.

The first petroleum gear lubricants were simply the residual products derived from refining straight mineral oils. They were widely referred to as compounds for many years even though many types were straight petroleum or mineral oil products. It was a loose application of the word compound for in petroleum parlance compound means a combination of a fixed or fatty oil with a petroleum oil. For the typical spur gear as employed on slow speed cement, steel mill and rubber machinery where rotational speeds do not exceed 100 R.P.M., these heavy bodied straight mineral oils sufficed. More fluid straight mineral oils of turbine grade in turn were better suited to high speed single helical and herringbone reduction gearing where pinion speeds may approach several thousand R.P.M. Textile machinery and machine tools were among the first to adopt these drives.

When automotive engineers designed a truly workable motor vehicle early in the century, gear design really began to progress. The spur gear and straight bevel gear were quite suitable to most of the other types of machines of that period, but the marine steam turbine and motor car required a type of gear which would run quietly at high speeds. The helical, herringbone and spiral bevel ideas served this purpose, the latter paving the way to subsequent development of the hypoid gear.

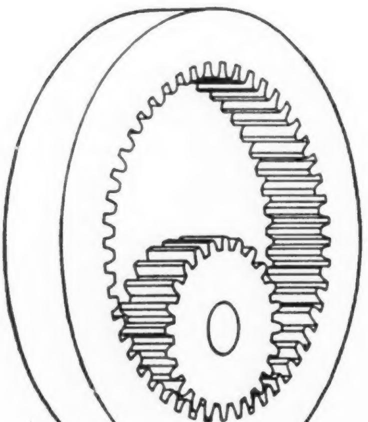
At one stage in the early development of gear lubricants the thought prevailed that by thickening a medium viscosity petroleum oil with a material which might or might not have much lubricating value, the latter would take up the shock loads on the gear teeth somewhat like a cushion. Too often these were of doubtful lubricating value since some of them had little ability to re-establish a lubricating film on the tooth surfaces between successive engagements of the teeth. Such a product may stay on the teeth when first applied, but after the teeth have meshed a few times it will either be forced to the base of the space between the teeth where it will probably remain packed, or the action of centrifugal force will cause it to be thrown off.

TYPES OF GEARS



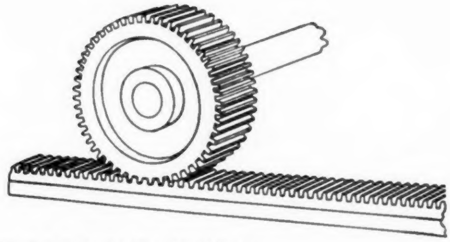
THE SPUR GEAR

A spur gear is a cylinder, wheel, or disk on the surface of which are cut parallel teeth each in a common plane with the axis. Spur gears are most commonly found on industrial machines, working under ordinary conditions, at moderate speeds and with medium pressures exerted upon the teeth.



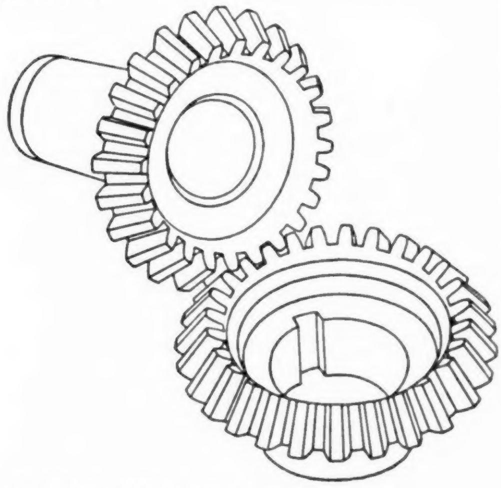
ANNULAR OR INTERNAL GEARING

An annular gear is internal in nature; it has parallel teeth similar to the spur gear, but cut on the inside rim or inner surface of a cylinder or ring. The companion pinion of an annular gear, however, must be a standard gear. Internal gear sets are often used for large speed reductions where the direction of motion may have to be reversed. The main driving element on certain types of tractors is a typical example of the use of gears of this type.



THE RACK AND PINION

The principle of gearing is also applied to the rack and pinion. The function of this device is to bring about reciprocating motion. The teeth on the rack or straight element are normally of the spur type. A worm or spur gear pinion meshes with the rack.



THE BEVEL AND SPIRAL BEVEL GEAR

In a bevel gear the teeth are cut on an angular surface, such as would be represented by a truncated cone. They are used for the transmission of motion between shafts with intersecting center lines to form an angle between each other. This is usually a full 90 degree angle with the shafts located at direct right angles with respect to one another. The spiral-bevel gear is also applicable to non-parallel shafting, when it is termed an angle drive; in appearance it approaches the spiral type of tooth.

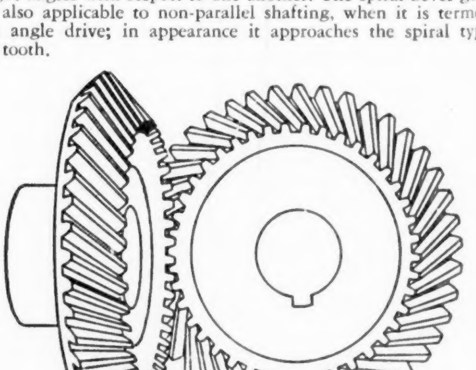
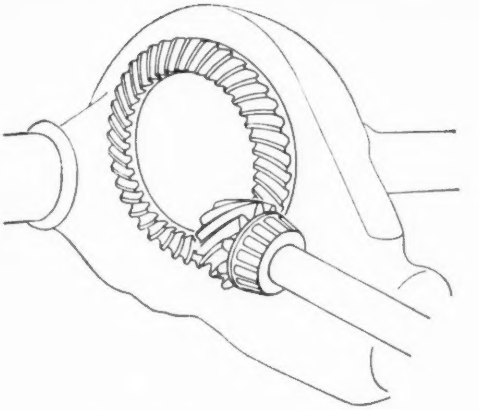


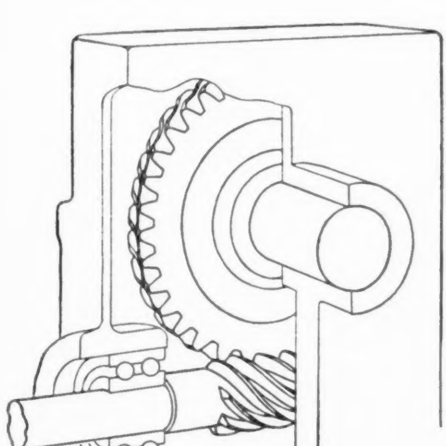
Figure 1

TYPES OF GEARS



THE HYPOID GEAR

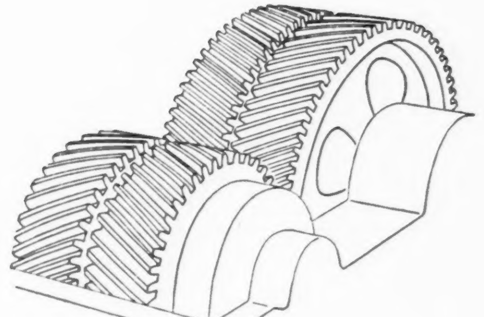
In contrast with the conventional spiral-bevel gear where motion is largely of a rolling nature, the hypoid develops a longitudinal sliding motion between the teeth of the pinion and ring gear. This greater sliding action between the teeth of a set of hypoid gears creates a wiping effect which, combined with high tooth pressure, may rupture the lubricating film unless the lubricant is manufactured to develop high load-carrying capacity.



WORM GEAR SETS

The two members of a worm gear set are known as the worm and the worm wheel, or gear. The worm resembles a screw, although it is really a special form of helical gear, and its teeth are referred to as threads.

The worm is usually made of a hard, wear-resistant steel; the worm wheel, which resembles a helical gear (except that it is throated, or curved on the face to envelope the worm partially), is preferably made of a grade of bronze having good bearing properties. The worm is normally the driver, and its action on the worm gear is quite similar to the action of a screw on a nut. Due to the wedge-like action of the worm thread on the gear tooth, it is relatively easy to obtain quiet operation with this type of gearing; it also provides a very wide range of speed reduction.



THE HELICAL AND HERRINGBONE GEAR

The helical gear resembles the spur gear in that the teeth are cut on a cylindrical body, but the helical gear differs from the spur gear in that the teeth are spiraled around the body, rather than formed parallel to the axis of the gear body. Spiraling the teeth provides smoothness of operation.

The herringbone gear resembles two helical gears having reversed directions of spiral, placed side by side, so that the teeth come together to form a chevron pattern. In general, helical or herringbone gears are used with parallel shafts. In the herringbone design, spiraling the teeth in both directions neutralizes end thrust. Herringbone gearing is generally used in enclosed drives, where fluid lubricants can be employed.

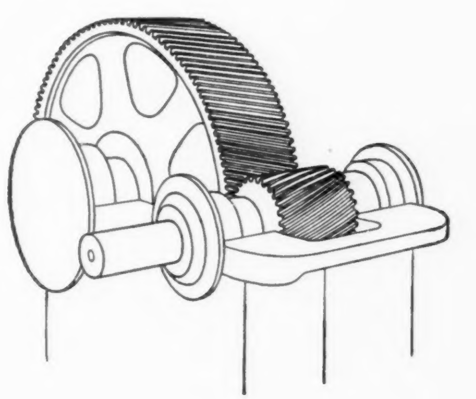


Figure 2

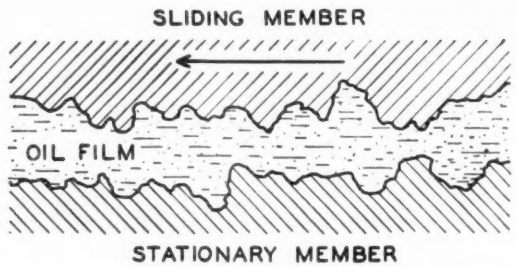


Figure 3 — With thick-film lubrication the moving parts are completely separated by an oil film. The roughness of the surfaces are greatly exaggerated for purposes of illustration.

When this occurs insufficient lubricant usually will remain on the gear tooth surfaces, consequently, boundary lubrication may develop and where pressures are sufficiently high tooth wear will result. The appearance of the teeth can be deceptive, for even though they may seem to have an oily surface, the film strength is not sufficient to prevent wear. The explanation is that as the teeth become disengaged, the tips, which have been forced down into such a lubricant when meshing wipe over adjacent tooth surfaces and leave an oily appearance although metal abrasion already has occurred.

LUBRICANT FILM-STRENGTH

The necessity for adequate film strength in a gear lubricant became apparent when speeds and tooth loads were increased and subsequently the protective ability of Extreme Pressure lubricants was demonstrated on hypoid gear tooth surfaces. Gear teeth, regardless of their design or the accuracy with which they are made, develop a combination of sliding and rolling motion as they pass into and out of mesh. Since sliding always prevails between gear teeth, accompanied so often by very high pressures which are comparable to those encountered in rolling contact bearings, maintenance of the lubricating film is an important requirement.

In order to understand where film-strength fitted into the program of developing the modern gear lubricants the types of lubrication which can exist must be discussed. They involve:

1. Thick-film or hydrodynamic lubrication
2. Boundary lubrication.

Thick-Film Lubrication

In thick-film lubrication the parts are completely separated by a film of oil so when one tooth surface slides over another the oil film will be sheared continuously as in Figure 3.

The term "film-strength" as applied to thick-film lubrication, therefore, has no significance. The oil film cannot be considered in terms of some material having resistance to puncture or which has tensile strength. It is a fluid material which supports the load entirely by hydraulic action, and the oil characteristic which controls this action is viscosity. As a result, the presence of film strength additives of phosphorus, chlorine, or sulfur compounds in the oil can serve little useful purpose during thick film lubrication.

If the viscosity is increased, the oil film becomes thicker and more work is required to turn the gears in and out of mesh. In other words, the friction is increased. However, if the oil viscosity is decreased, the film becomes thinner and although the work required then is less, the high spots on the tooth surfaces approach nearer to each other and the transition from thick-film to boundary lubrication is approached. Similarly, if the load is increased or the speed is decreased, the tooth surfaces approach each other and again the action approaches boundary lubrication.

Boundary Lubrication

When conditions of load, speed and oil viscosity are such that the oil film is too thin to separate the gear teeth completely, then the high spots may begin to touch each other as in Figure 4. Thick-film lubrication no longer exists and the condition termed boundary lubrication is approached. As the load is increased or the speed is decreased, more and more of the high spots tend to come in contact and the force required to turn the gears increases. What actually happens at the high spots and also what happens to the contacting surfaces involves both chemical and physical phenomena. The theory is that Extreme Pressure additives support the load by forming a chemical film or by forming an easily sheared film such as lead sulfide, lead chloride, etc.

Research has shown that certain materials termed oiliness or polar agents are effective in reducing friction under boundary lubrication conditions. These materials are high molecular weight organic compounds containing carbon, hydrogen and oxygen as compared to lubricating oils which contain only carbon and hydrogen. When one end of the lubricant molecule is highly reactive, it has the property of forming a powerful bond with a steel surface or may actually form soaps and enhance load carrying capacity.

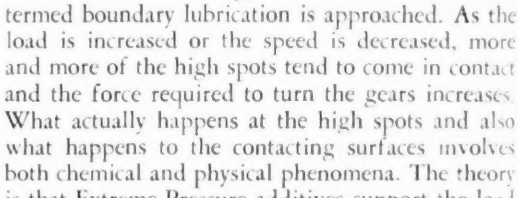


Figure 4 — With partial boundary lubrication, the oil film is so thin that some of the high spots of the sliding member touch the high spots of the stationary member.

Figure 5 — NORMAL WEAR
This condition refers to the gradual smoothing and polishing of the working surfaces resulting from the sliding and rolling action of the teeth. It is frequently spoken of as "running in". With proper design, manufacture and operation, a condition is reached after which wear practically ceases.

WHY AND HOW GEARS FAIL

When a gear tooth fails it may involve actual breakage of one or more of the teeth, or there may be failure of the tooth surfaces. Tooth breakage is rarely attributable to faulty lubrication. Change in metal structure, abuse or excessive overloading are more usually the cause. Lubricants which would otherwise be amply protective cannot insure against failure under such conditions, nor can they always keep the temperatures within reasonable limits. Abnormal temperatures from any source, can cause imperfect surface lubrication with resulting excessive friction. Then scoring and/or scuffing may develop, along with perhaps softening and cracking. Under such conditions, the temperature over the contact areas of the teeth has probably become high enough to reduce the viscosity of the oil film to such an extent that the lubricating value of the film on the teeth is negligible. If this continues, more friction, more heat, less lubrication and more tooth failures will result.

On exposed gears, the lubricant must be adhesive as well as viscous — otherwise the film cannot resist the action of centrifugal force. There is no continuous replenishment of lubricant on the surface by dip or spray as is possible with enclosed gears.

Where dealing with bath or dip lubricated gears, the lubricant is chosen so that at the operating temperature the viscosity will be sufficient to train with the teeth. If the oil is too light an insufficient amount may be carried by the dipping gear to the companion gear or worm. In this case, the cooling ability of the lubricant will be lost. Under such conditions, a worm gear for example, may run so hot as to cause the threads to soften and crack, or to result in wiping of the bronze teeth of the worm wheel. For this reason, some designers improve the adhesiveness of a worm gear oil by using a compounded product containing a polar agent. Other authorities feel that a lubricant containing lead naphthenate (which has mild E.P. properties) and which is non-corrosive to copper, bronze or steel, provides reduction in friction load, lower temperature at the interface surface and increased efficiency. In a worm gear, the rate of sliding is greater than in a spur, bevel or helical gear.

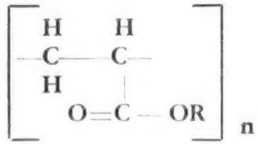
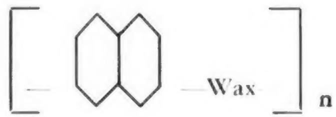
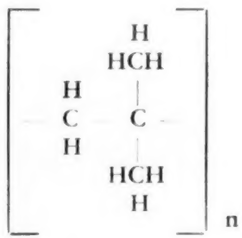
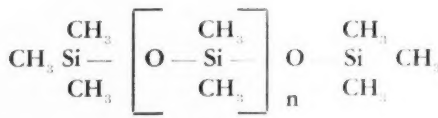
Wear

When the tooth surface of a gear becomes impaired, it may progress through several recognized stages. First, more or less abrasion or rubbing off of the metallic surfaces occurs. Spur, helical or bevel gears will often become smooth and highly polished during the initial stages of abrasive wear. To some extent this could be regarded as a "wearing-in" procedure. It is regarded as being related to the viscosity of the gear oil, as it is apt to occur more rapidly with lower viscosity lubricants. A heavier oil or one with E.P. characteristics will present a more durable film on the teeth and retard this type of wear. High tooth loads and low speeds also contribute to excessive wear if the viscosity of the oil is not chosen accordingly. Evidence of wear is most pronounced below the pitch line of the pinion if lubrication has been ineffectual. While abrasive wear is progressing the theory is that the fine metallic particles which are worn off the teeth, mix intimately with the oil film to develop a lapping action. The best "wearing in" or "running in" action is that which results in polished low friction surfaces with minimum of metal removal from the gear tooth surfaces. All this is accomplished by the proper selection of viscosity and additive combination in a suitable base oil.

Figure 6 — INITIAL PITTING
This term applies to the formation of small *pits* in the tooth surfaces, as large as the head of a pin or smaller, usually starting in the vicinity of the pitch line, and frequently occurring during the initial period of gear operation. *Pitting* should not be considered as detrimental, unless it advances beyond the *initial* stage. If *pits* occur gradually, and do not increase rapidly, they indicate a temporary condition and may disappear entirely in the course of normal wear.

TABLE I

GEAR OIL ADDITIVES

TYPE OF ADDITIVE	TYPICAL FORMULA OR COMPOUND	FUNCTION IN LUBRICANT
Pour Depressant High Mol. Wt. Polymer		Reduce the Pour Point or Channel Point of the lubricant so that it will flow freely at reduced temperatures.
or Wax Naphthalene Condensation Product		
Viscosity Index Improver High Mol. Wt. Resin		Improve the Viscosity – Temperature relationship of the lubricant to minimize viscosity spread over service temperature range.
Foam Depressant High Mol. Wt. Silicone Polymers		Prevent foam or accelerate foam collapse.

NOTE: In the above formulas, the following symbols are used:

R = an organic group composed of hydrogen and carbon.

n = indicates a number of like molecules condensed together to form a resin-like material.

Wax = high molecular weight paraffinic hydrocarbon.

Extreme Pressure and Polar Agents

Function	Type of Gear	Normal Operation	Heavy Duty Extreme Pressure Lub. Required
	Spiral Bevel	yes	
	Annular or Internal	yes	
	Helical or Herringbone	yes	

	Function	Type of Gear	Normal Operation	Heavy Duty Extreme Pressure Lub. Required
		Spiral Bevel	yes	
		Annular or Internal	yes	
		Helical or Herringbone	yes	
		Worm	yes	
		Rack and Pinion	yes	
Type 2 Non-Corrosive Type Sulfurized fat	Prevent welding by: forming an easily sheared film-iron sulfide.	Spur	yes	
		Bevel	yes	
		Spiral Bevel	yes (and break in)	
Type 3 Non-Corrosive Type Lead Soap Sulfur Phosphorus	Prevent welding by: (a) forming an easily sheared film: iron sulfide, lead sulfide, etc. (b) forming a low melting point phosphorus alloy.	Spur		yes
		Bevel		yes
		Spiral Bevel		yes
		Annular or Internal		yes
		Helical or Herringbone		yes
		Worm		yes
Polar Agent (optional)	Reduce friction: Metal to metal contact or between easily sheared films.	Rack and Pinion		yes
Type 4 Corrosive Type Lead Soap Active Sulfur	Prevent welding by: forming an easily sheared film: iron sulfide, lead sulfide, etc.	Hypoid	yes High speed— low torque with shock loading.	
Type 5 Non-Corrosive Type Chlorine Sulfur Phosphorus	Prevent welding by: (a) forming an easily sheared film: iron chloride. This action is catalyzed or speeded up by the presence of sulfur and its compounds. (b) forming a low melting point phosphorus alloy.	Hypoid	yes High speed— low torque	yes Low speed — high torque
Type 6 Non-Corrosive Type Lead Soap Sulfur Chlorine	Prevent welding by: forming an easily sheared film: iron sulfide and iron chloride. The formation of iron chloride is catalyzed by the presence of sulfur and its compounds.	Hypoid	yes High speed— low torque	yes Low speed — high torque
Polar Compound (optional)	Reduce friction: Metal to metal contact or between easily sheared films.			

Figure 7 — PROGRESSIVE PITTING
This type of failure is indicated when the formation of *pits* continues at an increasing rate, both as to number and size. A point may be reached when the unpitted areas of the tooth surfaces are insufficient to carry the load, and complete destruction of the tooth shape may occur, especially after continued operation at relatively high load, and over loading.

Scoring and Galling

These often follow abrasive wear due to actual metal-to-metal contact. Here wear is more severe and tearing of the tooth surfaces is evidenced. Normally this occurs in the direction of sliding. Scoring develops regardless of the hardness of the tooth surfaces, but it often may show more of a tearing nature and develop into galling with softer surfaces where total absence of any oil film has permitted welding to occur between the high spots of the tooth surfaces.

Welding

The theory back of this welding action, which, incidentally, led to the development of Extreme Pressure gear oils is of interest.

Figure 8 — ABRASION
This condition may be described as a general wearing away of the tooth surface at a comparatively rapid rate. It generally results from the presence of foreign matter such as dirt, grit, or metallic particles in the lubricant. It may also be caused by a breaking down of the material on the tooth surfaces, as for instance in cast iron gears. *Abrasion* appears as fine scratch marks up and down the tooth profiles closely distributed over the surfaces. Improper lubrication may result in *abrasion*.

In the case of steel on steel, the lubricant present, even the adsorbed polar molecules, cannot always prevent minute high spots from deforming and breaking off to form fresh surfaces of clean metal. When two freshly formed surfaces slide over each other the local temperature at these spots becomes very high because a considerable amount of heat must be dissipated over a very small area. As a result, welding takes place, and the rupture of the metal to form more fresh surfaces occurs.

So long as the high spots on the teeth are at all times separated by several molecular layers of oil there can be no wear. If, however, the mechanical attack at the contact areas by metals rubbing together becomes severe enough to remove the ultimate protecting film, the rubbing clean metals will

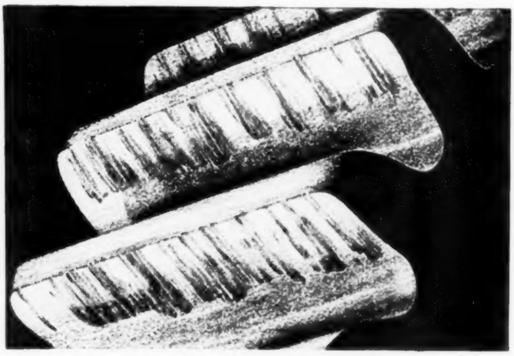


Figure 9 — SCORING
This condition results from excessive loading or inadequate lubrication. *Scoring* may occur even in gears which have been properly designed, manufactured and installed, when conditions of operation are such as to cause metal-to-metal contact. The tooth surfaces may be roughened only on small areas and on the same position on all teeth. This may be followed by a general disintegration of the surfaces, if abnormal conditions of operation are continued. *Scoring* in its initial stages may sometimes be eliminated by applying more effective lubrication, i.e. using a general purpose E.P. lubricant.

seize, possibly causing irreparable damage to the surfaces. This seizure, which is welding on a small scale, can become progressive to result in the gross removal of metal.

If conditions are right, more and more metal is torn off. By this time most of the prominent high spots have been removed and instead of welding of the small peaks of a few high spots, larger areas weld. This is aggravated as the speed and load is increased. Research has demonstrated that with the higher loads the maximum localized temperature is reached at a lower speed, and conversely at a high speed, the load required to reach maximum high spot temperature is lower than at slow speeds.

In other words, the volume or thickness of the oil film under the prevailing pressure and sliding velocity determines whether or not an E.P. lubri-

Figure 10 — GALLING
Galling is an aggravated condition of scoring caused by particles of metal torn out from the tooth surfaces in a manner that is sometimes referred to as *seizing* and *welding*. This condition is more likely to occur when two comparatively soft gears of the same hardness are operated together under heavy load conditions.

cant is necessary. When the oil film is too thin to prevent metal-to-metal contact, the use of an Extreme Pressure oil should be seriously considered. Beyond boundary lubrication, it is essential to counteract with additives the shock or intermittent loads as well as the continuous loads which develop at any speeds.

One of the most difficult problems of lubrication which has developed in recent years, for example, is in connection with hypoid gears. Intensity of load and speed of rubbing are such that a special lubricant is required. Wherever high power losses and wear prevail there is a problem. Under high loading the oil film between the high spots becomes extremely thin. So long as it exists at all there can be no clean metal contact, and therefore no abrasion, but this condition can only continue

Figure 11 — BURNING
This condition is indicated by discoloration of the tooth surfaces of the type associated with high temperatures. Such discoloration indicates that excessively high temperature has actually occurred, and may be caused by overspeed, overload or faulty lubrication. Burning may result in a reduction in the hardness of hardened steel gear teeth and worm threads, making them unsuited for carrying the specified load.

so long as the rate of removal of the film does not exceed its rate of renewal.

This explains why lubricants that are satisfactory for spiral bevel gears may not have sufficient Extreme Pressure characteristics for hypoids. The sliding action is more severe in hypoid gears, so consequently, for the same load, the contacting high spots of hypoid gears are more likely to reach welding temperatures. Industrial gearing need not be of the hypoid type to require an E.P. lubricant; loading is a factor.

In industry, where gearing is adequately proportioned in line with American Gear Manufacturers' Association practice, and housed, comparatively fluid lubricants are generally applicable. They are applied to the gear teeth and bearings either by

Figure 12 — ROLLING and PEENING
These terms refer to a plastic flow of the tooth surfaces, which may occur when the material in the gears is ductile in compression, and of insufficient hardness. *Scoring* may or may not be present. One effect of rolling is the formation of slight "fins" at the top edges and ends of the teeth. Rolling refers to that condition where plastic flow takes place due to heavy continuous loading: *Peening* where the load is intermittent resulting in a plastic flow of the material due to "hammer blows".

force feed lubrication or splash in contrast to automotive service where bath lubrication prevails.

Pitting

Pitting involves the formation of small pits in the tooth surfaces, usually starting in the vicinity of the pitch line, and frequently occurring during the initial period of gear operation.

Pitting is related to surface cracking; it is a fatigue failure. It involves actual removal of surface material to a depth dependent upon the localization of stress. While it occurs very often at low speeds and at low operating temperatures where high torque prevails it is not restricted to low speed.

Where constant repetitive shock loading or hammer action is induced by some action in the machine, a condition akin to fretting corrosion* occurs which can cause the teeth to pit.

*See "Fretting corrosion" article in Lubrication, March, 1948.

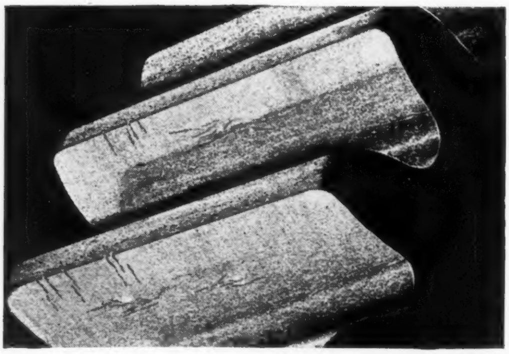


Figure 13 — CRACKING and CHECKING

Cracking refers to the occurrence of single or scattered cracks in the tooth surface which do not necessarily result in failure.

Checking refers to the formation of numerous and closely grouped cracks in the surface.

Cracking may result from loading and lubricating conditions causing excessive temperature fluctuations; and also from excessive hardness. *Checking* may result from several causes. The direction and arrangement of the *cracks* and *checks* usually indicate the probable causes. Frequently, *cracks* and *checks* can only be detected by etching or by the "magnaflux method". For cracks in fatigue failures, see *fatigue breakage*, Figure 17.

SELECTING GEAR LUBRICANTS

During the transition in gear design, gears, of course, had to be lubricated, even though there was no scientific procedure for ascertaining the most suitable viscosity for any or all cases. Practical experience over the years resulted in the development of a considerable variety of gear lubricants to meet the requirements stated above. Today they vary all the way from straight mineral oils to intricate mixtures. Any finely divided solid material which serves only as a thickener and has little or no lubricating value is not recommended for modern gearing. It may very well be deceiving in that an uninformed user may believe that his lubricant is suitable, when, in reality, it is giving comparatively poor protection against wear. The necessary adhesive characteristics also may be relatively low. As a result, when used under high-speed conditions, or wherever the gears may come into contact with water, acids, alkalis, or chemical fumes, the gear teeth may lose their protective film of lubricant, due either to its being thrown off by centrifugal force, or washed from the wearing surfaces.

APPLICATION AND FUNCTION OF ADDITIVES*

A gear oil additive may be defined as a chemical compound which either imparts new properties to the mixture or else enhances the properties which the oil already has.

*Definition of "additive" — while unquestionably the ingredients are chemical compounds, many commercial additives are mixtures, and sometimes the exact chemical structure of the active ingredients is uncertain.

The design of gear lubricants is not a simple problem but research conducted during the past two decades has provided a rather large amount of fundamental information which is very useful for meeting present day gear lubrication problems. However, it must be appreciated that many of the theories concerning the role of gear oil additives are not universally accepted and the skill and experience of the oil technologist is of considerable importance in this problem.

In the formulation of gear lubricants the additives used generally fall into fairly well defined groups depending on the type of gear and the conditions of operation involved. Table I shows this graphically though in a very simplified form.

General

The choice of Pour Depressants, Viscosity Index Improvers and Foam Depressants presents no particular problem because the types employed are also used in lubricating oils of all types. A particular selection may be influenced by the effectiveness of the additive as well as its cost.

Specific Gear Oil Additives

Selection of Extreme Pressure and polar additives is by far the most important phase of formulating gear oils and since so many materials are available for consideration it is important to relate the function of additives to general chemical types and avoid "trial and error" research.

Type 1. It is, of course, a well-known fact that straight mineral oils have given and continue to give satisfactory service on many types of gears under normal operating conditions — light load and low or high speed. Further comment on this type of gear lubricant is unnecessary.

Type 2. In the past and even today, a gear lubricant containing a sulfurized fat such as lard oil is

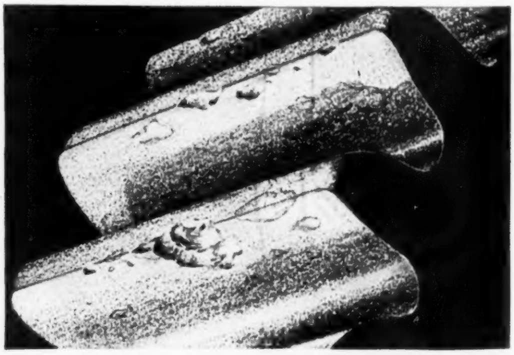


Figure 14 — CHIPPING

This term refers to the breaking off of portions of material at the edges or boundaries of the teeth. It may indicate excessive brittleness, when it occurs under normal load. Another term indicating this condition is *spalling*.

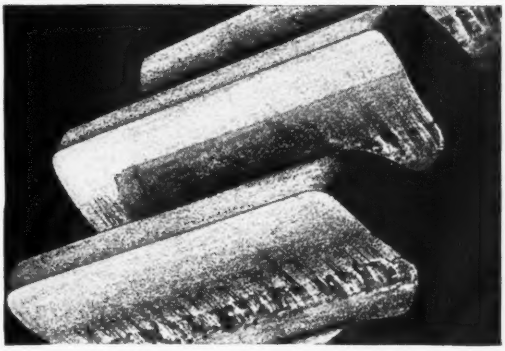


Figure 15 — GOUGING
This may occur in unhardened gears when there is interference between the flank of the driving pinion and the tip of the driven gear. The top edges of the gear teeth may gouge the material near the roots of the pinion teeth. A similar effect may occur between the edge of a hardened worm thread and the teeth of a worm gear.

specified for spur, bevel or spiral bevel gears for "run-in" or "break-in" purposes. After the initial fill a straight mineral oil is specified for normal operating conditions.

With sulfurized fats, it is intended that sulfur be available to prevent welding by forming iron sulfide at the metal to metal peak contacts shown in Figure 3. The sulfur must be sufficiently stable to prevent staining of copper and brass, hence the "non-corrosive" designation.

Type 3. A somewhat more complex formulation involves the use of lead, sulfur and phosphorus and is an application of a modern theory of the function of Extreme Pressure agents. This class of gear lubricant is intended for many types of gears operating under conditions of high load and/or speed. The additives must be chosen to be active chemically under these conditions. Welding at high temperature is prevented by the formation of an easily sheared film of iron and lead sulfide and also by the formation of a low melting point phosphorus alloy. In this manner, welding is prevented over a range of operating conditions. Oftentimes, the mere prevention of welding is not sufficient for satisfactory lubrication and a polar compound must be used to reduce friction and afford acceptable operating temperatures.

Type 4. The adoption of the hypoid gear by the automotive industry for high speed/low torque condition required a gear lubricant that would prevent welding under conditions differing radically from those encountered before. In this type of gear the tooth pressure is high, coupled with a pronounced wiping effect. Thus it is easy to visualize that the proper lubrication of the hypoid gear in high speed/low torque conditions must be accomplished under new conditions of temperature and pressure. To do this it has been found necessary to choose additives to prevent welding but — and this is the important point representing development and application of a new theory — the *temperature* and *rate* of formation of the easily sheared film must be regulated and controlled. This can be done by using a lead soap and *active* sulfur. This class of gear lubricant causes high wear under high torque — low speed conditions. The active sulfur is the key to this type of formulation. The sulfur is bound in a rather loose chemical manner and controlled to be available at the required temperature and in the proper amount. It should be obvious that sulfur when present at this high level of activity would stain copper — hence the designation — corrosive type. This type of lubricant is particularly effective when shock type loading is a factor.

Type 5. With the widespread application of the hypoid gear in passenger car and truck service — high speed/low torque and low speed/high torque conditions — it was necessary to modify the lubricant described in (4) to accommodate the more severe conditions of tooth pressure, wiping action and temperature and to prevent wear. Again a more specialized application of the theory that the *temperature* and *rate* of formation of the easily sheared film for a particular range of operating conditions was required.

This type of gear lubricant is actually the "all-purpose" or "multi-purpose" type as covered by Military Specification MIL-L-2105, 7 April 1950—Universal Gear Lubricant. This specification was developed as the result of cooperative effort with the automotive manufacturers and the oil industry. The specification is significant because two full-scale laboratory axle tests form a part of the qualification testing of lubricants submitted for Ordnance Department approval against MIL-L-2105.

Figure 16 — OVERLOAD and BREAKAGE
This term refers to gear tooth breakage caused directly by an unexpected shock or overload — due for instance to the jamming of other machinery — of a nature which cannot be attributed to improper design or faulty manufacture.

Figure 17 — FATIGUE and BREAKAGE
This term refers to tooth breakage as a result of repeated loading, and is usually characterized by the formation of *cracks* at highly stressed locations, which progressively extend in area and depth until failure occurs. *Fatigue breakage* is not necessarily an indication of poor design or faulty manufacture. It merely means breakage after a large number of repetitions of load, as distinguished from overload breakage, which may be the result of a single application, or a comparatively few applications of excessive load. In fact, it is the practice in automotive and aircraft design to proportion the gears, so that they will fail by *fatigue* after they have fulfilled their rated length of service. It is usually possible to ascertain from the character of the surfaces of the fracture, if the failure is from fatigue.

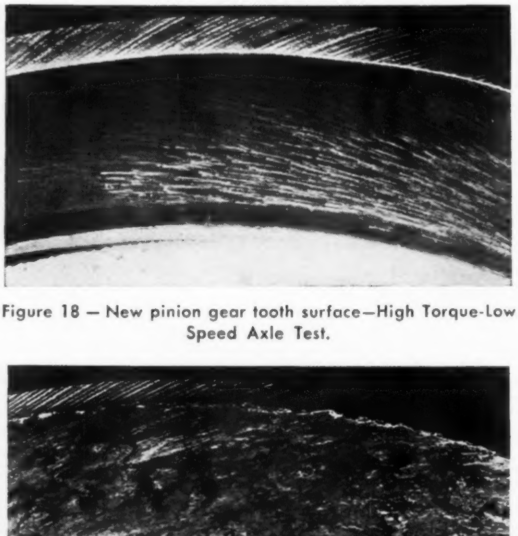


Figure 18 — New pinion gear tooth surface—High Torque-Low Speed Axle Test.

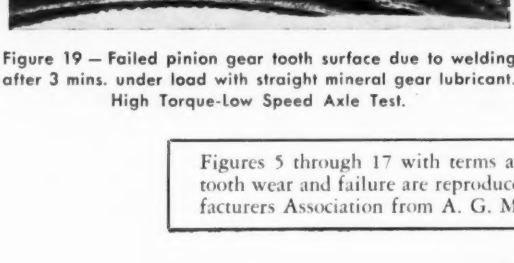


Figure 19 — Failed pinion gear tooth surface due to welding after 3 mins. under load with straight mineral gear lubricant. High Torque-Low Speed Axle Test.

It is apparent from Figures 18 and 19 that something more than straight mineral oil is required — i.e. additives.

In the formulation of lubricants for this service, additives containing chlorine, sulfur and phosphorus are employed. The essential variation from (4) is that the formation of iron chloride which prevents welding is catalyzed or speeded up by sulfur to insure satisfactory service under very severe operating conditions. The role of phosphorus is similar to that previously described.

Type 6. This type of gear lubricant is similar to that in (5) since the lubrication of hypoid gears is the primary purpose. From an additive standpoint the principal change is the inclusion of a lead soap and the omission of phosphorus. This type of lubricant can be made to meet 2-105B and there is evidence that it will handle more severe operating conditions than the conventional Universal Gear Lubricant. This difference can be shown in controlled road testing procedures. It has been found that a lubricant which will give satisfactory service in a severe road test involving a 1½ ton tractor-trailer unit (24,000 pounds gross) operated at 19 MPH average over mountainous terrain for 3000 plus miles will not necessarily pass 2-105B requirements. This statement is not made from the standpoint of criticism. Instead it is believed to support the theory that gear lubricant additives must be chosen on the basis of chemical activity and this property must be fitted to predetermined operating conditions.

CONCLUSION

From the foregoing simplified description of how various types of gear lubricants are designed for specific application it should be apparent that the successful lubrication of all types of gears is the result of

(a) significant progress in understanding the function of Extreme Pressure additives,

(b) ability to select additives to perform satisfactorily at different severity levels of operation,

(c) proper appreciation of the importance of selecting the proper gear lubricant.

Admittedly, knowledge of gear lubricant additives is not as complete as desired and considerable fundamental research remains to be done if additives are to be selected with confidence and costly field and full scale laboratory testing is to be eliminated. The petroleum industry is devoting much effort to the solution of this problem.

Figures 5 through 17 with terms and definitions used in designating gear tooth wear and failure are reproduced by courtesy of American Gear Manufacturers Association from A. G. M. A. Tentative Standard Nomenclature.

Printed in U. S. A. by
Salley & Collins, Inc.
305 East 45th Street
New York 17, N. Y.

TEXACO LUBRICANTS FOR INDUSTRIAL GEARS (Cont'd)

TYPE OF GEAR	DESCRIPTION	AMBIENT TEMPERATURES	NORMAL OPERATION	HEAVY DUTY, WHERE EXTREME PRESSURE LUBRICATION REQUIRED	IN PRESENCE OF WATER OR CHEMICALS
WORM	Gears enclosed, casings oil tight, bearings separately lubricated.	Below 40° F.	Regal Oil PC (R&O) Thuban 80	Meropa Lubricant—1	
		40° to 100° F.	Honor Cylinder Oil Cavis Cylinder Oil 650T Cylinder Oil Thuban 90 Regal Oil G (R&O)	Meropa Lubricant—3	
		Above 100° F.	Honor Cylinder Oil Cavis Cylinder Oil Thuban 90 or 140 Regal Oil G (R&O)	Meropa Lubricant—3 or 6	
	Gears enclosed, casings oil tight, gear lubricant to serve bearings as well.	Below 40° F.	Regal Oil PC (R&O) Thuban 80 or 90	Meropa Lubricant—1 or 3	
		40° to 100° F.	Honor Cylinder Oil Cavis Cylinder Oil 650T Cylinder Oil Thuban 90 Regal Oil G (R&O)	Meropa Lubricant—3	
		Above 100° F.	Honor Cylinder Oil Cavis Cylinder Oil Thuban 90 or 140 Regal Oil G (R&O)	Meropa Lurbicant—3 or 6	
	Gears entirely exposed, hand lubricated.	Below 40° F.	Regal Oil G (R&O) Thuban 90 or 140	Meropa Lubricant—3 or 6	
		40° to 100° F.	Thuban 140	Meropa Lubricant—6	Crater 1-X or 2-X Fluid
		Above 100° F.	Thuban 140 Crater 0, 1 or 2-X Fluid	Meropa Lubricant—6	Crater 1-X or 2-X Fluid
RACK AND PINION	Gears exposed, bath lubricated.	Below 40° F.	Regal Oil G (R&O) Thuban 90	Meropa Lubricant—3	
		40° to 100° F.	Thuban 140	Meropa Lubricant—6	Crater A
		Above 100° F.	Thuban 140 or 250	Meropa Lubricant—6 or 7	Crater A
	Teeth entirely exposed, hand lubricated.	Below 40° F.	Crater 00, 0, 1, or 2-X Fluid	Meropa Lubricant—6	Crater A, 1-X or 2-X Fluid
		40° to 100° F.	Crater 1, 2 or 2-X Fluid	Meropa Lubricant—7 or 8	Crater 1-X, 2-X or 2-X Fluid
		Above 100° F.	Crater 3 or 5-X Fluid	Meropa Lubricant—8 or 10	Crater 2-X, 5-X or 2-X or 5-X Fluid
	Teeth exposed, bath lubricated.	Below 40° F.	Regal Oil G (R&O) Thuban 90 Crater 00, or 2-X Fluid	Meropa Lubricant—3	Crater A
		40° to 100° F.	Thuban 140 Crater 00, 0 or 2-X Fluid	Meropa Lubricant—6	Crater A, 1-X or 2-X Fluid
		Above 100° F.	Thuban 140 or 250 Crater 0 or 2-X Fluid	Meropa Lubricant—6 or 7	Crater A, 1-X or 2-X Fluid

NOTES: The above recommendations are naturally more or less general based on average pressures and for small to medium sized gears:

1. ***In case of light loads or high speeds:*** **Use next lighter grade of gear lubricant.**
2. ***If gears are very large:*** **Use somewhat heavier grade than that recommended above.**
3. ***Meropa Lubricants*** **are highly resistant to water and should be recommended where both a water resistant and an EP lubricant is desired.**
4. ***For cast gears:*** **Use the next heavier grade of gear lubricant recommended.**
5. ***Texaco Craters*** **under certain conditions are recommended for enclosed gears and exposed worm gears.**
6. **Should ambient temperatures be extremely low or high, or should any uncertainty exist as to the correct lubricant recommendation for a specific application, consult your local Texaco Lubrication Engineer.**

Note: When Texaco Crater Fluid is used, the usual precaution with products of this type should be employed.